Helicopter Life Substantiation: Review of some USA and UK Initiatives

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ABSTRACT

Military operators normally undertake programs to substantiate the fatigue lives of life-limited components in their major helicopter fleets. During recent visits to military helicopter representatives in the USA and the UK, the author discussed the motivation and the technical approach adopted by these operators for helicopter component life substantiation. Issues and programs of particular relevance to the Australian Defence Force are examined in this document.

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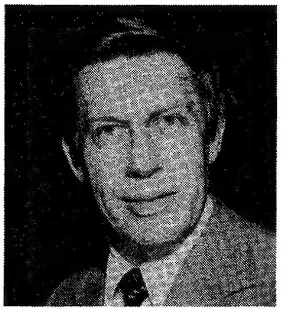

Mr Ken Fraser joined the Aeronautical Research Laboratory (as it was then known) in 1959 after graduating with honours from the University of Melbourne with a Bachelor of Electrical Engineering Degree. Since that time he has worked in various aeronautical fields including crash data recording, weapon kinematics, turbine engine health monitoring, turbine engine control and helicopter life assessment. He was involved in the development and flight demonstration of the world-first "black-box" aircraft crash data recorder which recorded cockpit voice and flight data on a magnetic wire medium. He developed a system for in-flight monitoring of the accumulated fatigue damage to heavily loaded helicopter gears; it was the first time a full fatigue damage calculation, which included component strength characteristics, had been performed during flight in a helicopter. Currently he is a Principal Research Scientist who manages helicopter fatigue life assessment work (structural and mechanical) undertaken by the laboratory on behalf of the Australian Defence Force. He pioneered the setting up , and is now a member, of an Australian Defence Organisation (including all three Services) Working Party which is providing guidance on the applicability of accident data recorders and HUMS (Health and Usage Monitoring Systems) to Australian Defence Force helicopters.

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EXECUTIVE SUMMARY

1. This review draws together insights gained from an examination of specialist views on the justification for military helicopter component fatigue life substantiation and the suitability of the methods used. These views were conveyed in discussions or correspondence with the author, or in published works. Special attention was given to U.S. Army Black Hawk, U.S. Navy Seahawk and RN/RAF Sea King component life substantiation programs. These programs are of special relevance to the ADF as similar Black Hawk and Seahawk aircraft represent lead aircraft fleets for the ARA and the RAN respectively while life extension of the RAN Sea King for a maritime utility role is to proceed. The severe usage of the ARA Black Hawk, as indicated by a pilot questionnaire usage survey conducted in 1993, has placed considerable urgency on the undertaking of a quantitative life substantiation program to better define the usage severity for that helicopter.

2. Military helicopter operators in the USA and UK have adopted policies to substantiate the design lives of components in their major fleets, usually by undertaking in-flight parameter measurement programs. Life substantiation programs usually involve the fitting of monitoring equipment in a small number of helicopters whose operations are representative of fleet operations. The duration of the data collection would typically be about 200 flying hours per aircraft in the measurement program.

3. Military operators in the USA and the UK consider in-flight data measurement programs to be superior to pilot questionnaire usage surveys. However the latter are undertaken in some instances because they are less costly. Questionnaire forms are often used to provide supplementary data in support of in-flight measurement programs.

4. Helicopter life substantiation programs are undertaken to ensure component retirement times are conservative. These programs may result in the shortening of the retirement times for some components if measurements indicate that their loading is more damaging than had been assumed. Component life extension, based on the results of a substantiation program, is viable only if a reliable and sufficiently large data set is available.

5. The life substantiation method adopted by military helicopter operators in the USA differs significantly from that employed by operators in the UK. In the USA the most common approach is to measure the flight condition usage spectrum and recalculate lives based on the relationship between flight condition and component life expenditure. That relationship is derived from the manufacturer's loads survey on the prototype helicopter. In the UK the most common approach is to measure the significant flight loads and re-calculate lives directly.

6. Some integrity problems which the U.S. Army and the U.S. Navy have experienced with their Black Hawk and Seahawk helicopters, respectively, are outlined in the report.

7. In the future, military operators are likely to purchase helicopters with permanently installed Health and Usage Monitoring Systems (HUMS). While the "usage" element of currently available systems is deficient, R&D moves afoot should rectify this situation before the turn of the century. When fleetwide quantitative usage data become available from HUMS, the process of component life substantiation, or component retirement according to actual usage, will be streamlined.

CONTENTS

ABBREVIATIONS

AATD	Aviation Applied Technology Directorate (U.S. Army)
ADF	Australian Defence Force
ARA	Australian Regular Army
AMRL	Aeronautical and Maritime Research Laboratory (part of DSTO)
ATCOM	Aviation and Troop Command (U.S. Army)
COG	Centre Of Gravity
CRT	Component Retirement Time
DC	Direct Current
DSTO	Defence Science and Technology Organisation (within Australian Defence Department)
EULMU	Engine Usage Life Monitoring Unit (manufactured by GPAv)
FCM	Flight Condition Monitoring (defined for use in this document)
FFT	Fast Fourier Transform
FLM	Flight Loads Monitoring (defined for use in this document)
EDMS	Engine Distress Monitoring System
GPAv	General Electric / Plessey Avionics
HALMARS	Helicopter Automatic Load Monitoring and Recording System
HCF	High Cycle Fatigue
HM	Health Monitoring (defined for use in this document)
HODR	Helicopter Operational Data Recording
HUM	Health and Usage Monitoring
MDHC	McDonnell Douglas Helicopter Company
NAWC	Naval Air Warfare Center (Trenton)
R&D	Research and Development
RAAF	Royal Australian Air Force
RAF	Royal Air Force
RAN	Royal Australian Navy
RN	Royal Navy
SUM	Structural Usage Monitor (a joint development of Canadian Marconi and Sikorsky)
SUMS	Structural Usage Monitoring System (a GPAv development)
UK	United Kingdom
UM	Usage Monitoring (defined for use in this document)
U.S.	United States *(of America)*
USA	United States of America
USD	United States Dollar
WHL	Westland Helicopters Limited

1. INTRODUCTION

At the time a fleet of helicopters is first delivered to a customer, the retirement times of fatigue life-limited components are based on component strength data, the results of a flight loads survey on the prototype helicopter and an *assumed* in-service usage spectrum. For helicopters, small changes in the level of loading can translate into large changes in the safe lives of fatigue life-limited components. This high sensitivity of component lives to changes in the load spectrum together with doubts regarding the validity of the assumed usage spectrum contribute to a concern by operators for the validity of their component retirement schedule. It is common practice for military operators to undertake programs to quantify their severity of usage and to substantiate their component retirement schedule after their aircraft are brought into service.

Most of the helicopter types operated by the Australian Defence Force (ADF) are also in military service in the USA or the UK. In a recent visit to these countries, the author discussed matters related to helicopter component life substantiation with military operator representatives and researchers. Special attention was given to U.S. Army Black Hawk, U.S. Navy Seahawk and Royal Navy (RN) / Royal Air Force (RAF) Sea King component life substantiation programs. These programs are of special relevance to the ADF as the Black Hawk and Seahawk represent lead aircraft fleets for the Australian Regular Army* (ARA) and the Royal Australian Navy (RAN) respectively and life extension of the RAN Sea King for a maritime utility role is to proceed. This document reviews the motivation, technical approach and status of these programs and also provides comments on the following related topics:

- Advanced structural usage monitoring concepts.
- Some integrity problems which the U.S. Army and the U.S. Navy have experienced with Black Hawk and Seahawk helicopters.

2. COMPONENT FATIGUE LIFE SUBSTANTIATION OVERVIEW

2.1 General

Helicopter component fatigue life substantiation reviewed in this section refers mainly to programs in which the mission severity of a fleet of helicopters is assessed by making suitable measurements for a limited period (typically about a year) on a small sample of helicopters engaged in duties representative of fleet operations. This form of data collection is frequently referred to as *usage monitoring,* but some tend to reserve the *usage monitoring* terminology for systems which are permanently installed fleet-wide. Some discussion on "true" monitoring systems intended for permanent installation is provided in Sec. 3.

* The Black Hawk life substantiation program is of special interest to the Royal Australian Air Force (RAAF) as it has the airworthiness responsibility for Army aircraft in Australia.

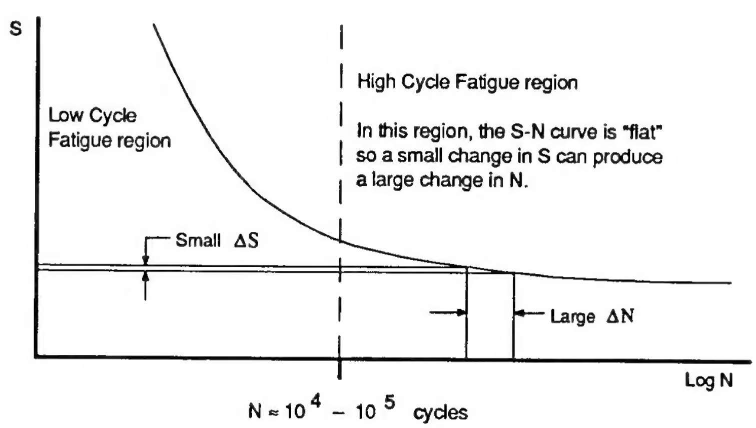
2.2 Life Substantiation Program Motivation

At the time a helicopter is first delivered to a customer the Component Retirement Time (CRT) schedule for fatigue-critical components is based on:

- Component strength data.
- Results of manufacturer's load survey (prototype qualification test aimed at measuring the maximum loads applicable to each flight condition).
- Design usage spectrum (assumed in-service flight condition and gross weight distribution).

A concern that in-service usage may be more severe than that defined in the design usage spectrum provides the main motivation for military operators to undertake life substantiation programs. Such programs normally involve in-flight measurement of parameters to allow flight conditions to be identified. A typical set of parameters for this purpose would be airspeed, altitude, air temperature, attitudes, rate of turn, vertical acceleration, engine torque and rotor pitch control positions. Some direct load measurements are often performed as well.

When assessing the impact on CRTs of the manner in which the helicopter is used, it is not only important to detect that a particular flight condition has been entered but also to measure the time spent in the condition. In a helicopter, dynamically loaded components experience cyclic loading at the rotor fundamental frequency (typically about 4 Hz for the main rotor and 20 Hz for the tail rotor), or multiples thereof. This "high" frequency loading leads to High Cycle Fatigue (HCF) being the failure mode of greatest significance for helicopter components. The region of interest on the S-N curve (number of cycles N to failure as a function of stress level S) for HCF is very "flat" (small change in load translates as a large change in safe life). This behaviour is illustrated in the diagram below. The high sensitivity of safe life to changes in load severity provides additional impetus for military operators to check whether their CRT schedule is conservative.



Military operators generally acknowledge that their helicopters are operated in a relatively severe manner consistent with their use in a combat role or in a combat training role. In meeting the demands of the military role, it is likely that the helicopter will be flown to the extremes of its operating envelope. For this reason, component fatigue life substantiation programs have assumed greater prominence for military operators than for civil operators.

2.3 Military Operator Policy on Life Substantiation

Military operators in the UK and the USA have policies which define a requirement to substantiate the CRTs of helicopter components. These policies tend to streamline the process of justifying the undertaking of such programs. Standard practice is to reduce lives on some components if actual usage is more severe than that defined by the design spectrum. On the other hand, substantiation programs often do not seek to extend component lives and hence "pay for themselves". Some operators indicated they would be prepared to consider life extensions if the sample size for the measurement program was sufficiently large. The cost of undertaking a life substantiation program needs to be budgeted for at the time of purchase of the aircraft or at some time thereafter.

2.4 Pilot Questionnaire Approach to Life Substantiation

Both the U.S. Army and the U.S. Navy have undertaken pilot questionnaires to help determine the severity of helicopter usage. Normally the questionnaires are undertaken on a fleet-wide basis. Generally the military helicopter operators visited felt that the questionnaires could yield useful information provided the right questions were asked but there were some reservations about their effectiveness. All indicated a preference for programs involving the in-flight measurement and logging of relevant data but admitted that the high cost of such programs presented difficulties. The points were made that questionnaires must be simple and that the best results are achieved if engineers ask questions which have engineering impact. The U.S. Army has conducted questionnaire surveys for the Cobra and the Huey, and one was being organised for the Apache during 1992. The U.S. Navy has undertaken questionnaire surveys for the CH-53A/D, AH-1W, VH-3, VH-60 and HH-60. The author gained the impression that the pilot questionnaire approach is more likely to be used for:

- Small fleets.
- Fleets which are engaged in "light" duties.
- Fleets whose operations comprise only a small number of sortie types.
- Interim indication for large fleets before undertaking a quantitative usage survey.

2.5 Substantiation Methods Involving Automatic Logging of In-Flight Data

The methods adopted by the military operators in the UK and the USA can be divided into two major categories. The first method, generally adopted by the U.S. operators, seeks to measure the severity of usage via *Flight Condition Monitoring* (FCM) and the second method, generally adopted by the UK operators, is to measure the severity of usage via direct *Flight Loads Monitoring* (FLM). While these represent the major thrusts of the two methods there is usually some overlap.

Flight Condition Monitoring Method

About 12 parameters need to be logged for flight condition identification. The number of defined conditions varies from manufacturer to manufacturer and from helicopter to helicopter, and would be typically in excess of 50. With this method, considerable reliance is placed on the validity of the manufacturer's loads survey (which is used to determine the

maximum component loads produced in each of the defined flight conditions). To reduce the level of this reliance, some programs extend the parameter list to include the direct measurement of a limited set of loads. The addition of these load parameters also helps resolve a concern about whether the loads developed when the helicopter is flown by military pilots are higher than those developed during the manufacturer's loads survey.

The recognition of flight conditions associated with low speed manoeuvres has presented major difficulties because airspeed sensors in common use throughout the industry are generally incapable of making reliable measurements below about 30 knot. The problem becomes particularly significant because the loading associated with the entry and exit from low speed manoeuvres often involves fatigue penalties.

Notwithstanding the above, the logging of flight condition recognition parameters is generally relatively simple because sensors for many of the parameters form part of the standard aircraft circuits. On the other hand, direct load measurements require specially fitted sensors and the measurements can be quite difficult. It is essential that gross weight be logged (either manually or automatically) when the FCM method is used.

Flight Loads Monitoring Method

The basic rationale behind the FLM method is to directly measure a number of loads from which all the fatigue-critical loads can be derived. Typically 10 directly measured loads would be used to substantiate about 40 failure mode features. Provided the loads are measured reliably, this method allows optimum confidence in the program findings as no reliance is placed on the manufacturer's loads survey. This approach, which is outlined by Holford [1], has been adopted by the UK military operators over a long period.

This method does not require the recording of flight condition parameters or gross weight. However, as a secondary aim, the UK operators see an advantage in being able to identify those manoeuvres which have the greatest fatigue significance. Such identification may enable some fatigue-critical manoeuvres to be avoided or reduced in duration or severity. To assist with the identification of the critical manoeuvres, flight condition parameters and gross weight are normally logged.

The main concern regarding this method is the difficulty in making direct load measurements, particularly on rotating components.

2.6 Status of Programs of Special Interest to the Australian Defence Force

Three life substantiation programs of special interest to the ADF were discussed. These are the RN/RAF HODR (Helicopter Operational Data Recording) program for Sea King helicopters, the U.S. Army SUM (Structural Usage Monitor) program for the UH-60A and UH-60L Black Hawk helicopters, and the U.S. Navy SUM program for the SH-60B and SH-60F Seahawk helicopters. In respect of these programs, the analysis of the data collected for the RN/RAF program was completed by WHL and Rolls Royce in 1993, the findings [2] of the U.S. Army program were made available to the RAAF in 1992, and the U.S. Navy measurement program was completed early in 1994.

RN/RAF Sea King HODR Program

Five Marks of the Sea King aircraft (Mark 2, 3, 4, 5, and 6) were involved in the HODR program.

In support of the HODR program two questionnaires were completed. The first form, which is very simple, was used fleet-wide to check whether the sortie distribution for the aircraft involved in the HODR measurement program was representative of fleet operations. The second form, completed only for the aircraft involved in the measurement program, is more detailed and includes the logging of such information as gross weight and COG position.

The Plessey Model PV1820E[3] Structural Usage Monitoring System (SUMS) was used for the Sea King HODR program. The SUMS used are variants of the PV1820D models* held at AMRL. An overall sampling rate of 256 Hz was used. Ten loads were directly measured by strain gauges in this program. Load values were converted to two "DC" signals representing the mean and the amplitude of the measured vibratory loads. The rate of application of the vibratory loads was inferred from known rotor rotational speeds. An auxiliary Model PA3014[4] Signal Conditioning Unit was used to provide input signal filtering and conversion to a 0 - 5 volt range, and to convert the four-wire synchro input signals to one-wire outputs.

Slip rings, which normally transfer blade-fold actuator signals, were used to convey main rotor loads, sensed by strain gauges, to the fixed instrumentation. Problems arose on some aircraft and it was found necessary to clean the slip rings once a week. The telemetry system used for transferring tail rotor torque measurements worked well but some sensitivity to radar signals was experienced.

Some problems were experienced with the use of old magnetic tape cassettes but new ones performed satisfactorily. An in-flight change-over of tapes was used when the flight duration exceeded the 2.25 hour recording limit.

U.S. Army UH-60A/UH-60L Black Hawk Structural Usage Monitoring Program

The U.S. Army undertook a structural usage monitoring program on one UH-60L and two UH-60A Black Hawk helicopters, . The monitoring program began in July 1989 when a UH-60A Black Hawk, based at Ft Rucker, Alabama, was fitted with a Structural Usage Monitor[5,6,7,8] (SUM). Data collection continued on this Black Hawk, known as Bearcat 8, until the end of the year after which the SUM was removed. In mid-1990, two more Black Hawks, also based at Ft Rucker, and known as Bearcat 6 and Bearcat 7, were fitted with SUMs. Data were again collected over a six-month period.

Although one of the aims of this program was to substantiate the lives of Black Hawk components for U.S. Army operations, it was pointed out by Immen[9] that the main motivation for this program was to test a system which might eventually be used for monitoring component lives according to aircraft serial number.

* AMRL holds three PV1820D Engine Usage Life Monitoring Units (EULMUs). GPAv indicated that these units can be upgraded to meet the PV1820E specification.

The SUM used in this program is a joint development of the Canadian Marconi and the Sikorsky companies. It provides in-flight recognition of flight conditions and logging of the time spent in each. Molnar [10] (Sikorsky) indicated that the on-board flight condition recognition software and the ground analysis system had worked well in this program, although the difficulty of accurately measuring airspeed below about 30 knot was a limitation.

Six direct load measurements were included in this program, two in the rotating system and four in the dynamic system. Loads were converted to two "DC' values (maximum and minimum), similar to the approach used in the HODR program. Major difficulties were experienced with these load measurements. Since Sikorsky had not intended to use the loads data for life substantiation purposes, the effect of a lack of reliable loads data was minimal from Sikorsky's point of view. However the lack of reliable loads data prevented a comparison being made of the maximum loads generated in each flight condition with those generated in the manufacturer's loads survey. This latter comparison was one of the U.S. Army's aims of the SUM program.

Sikorsky analysed the data collected in this SUM program and reported its findings [2] to the U.S. Army. AMRL was asked by the RAAF to comment on the findings* contained in this report with special attention to any implications for the S-70A-9 Black Hawk operated by the Australian Regular Army (ARA). AMRL's analysis of these findings has been documented [11].

U.S. Navy SH-60B Seahawk Structural Usage Monitoring Program

More recently, the U.S. Navy undertook a quantitative life substantiation program on six SH-60B Seahawk helicopters. SUM systems [8] (similar to those used by the U.S. Army for the Black Hawk life substantiation program) were used for collecting data in this program. However more parameters were measured in the Navy program than in the Army program, and some extension of the airborne hardware was necessary. Data collection for the U.S. Navy program was completed early in 1994.

Barndt [12] indicated that the U.S. Navy will collect data on each of the aircraft for a period of six months and it is expected that these data will be fully processed by Sikorsky two months later. The database will be built up as the data are received.

Barndt indicated that the decision to measure some flight loads came from the Navy, not from Sikorsky. The approach will be to check whether the measured load severity agrees with that measured by Sikorsky in its loads survey. U.S. Navy staff defined the set of loads to be measured based on their applicability to the components of greatest concern.

The RAN has requested AMRL to comment on the findings, when available, in the context of their relevance to the operation of the S-70B-2 Seahawk helicopters operated by the RAN. The findings are also of general interest to the ARA and the RAAF, the operator

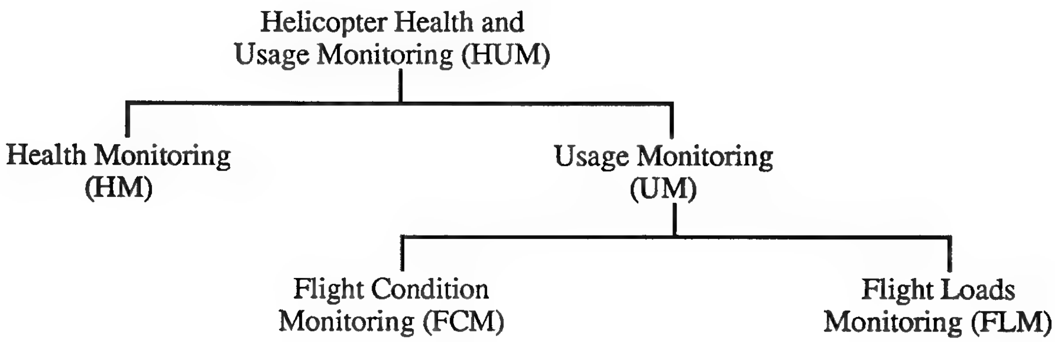
* The findings are also of general interest to the Royal Australian Navy (RAN) since it operates the S-70B-2 Seahawk which has much structural and mechanical commonality with the Black Hawk.

and airworthiness authority respectively, for the S-70A-9 Black Hawk which has much structural and mechanical commonality with the Seahawk.

3. HELICOPTER STRUCTURAL USAGE MONITORING

Helicopter usage monitoring is a term which is applied to a variety of techniques and methodologies to determine how severely a helicopter is flown. By quantifying the severity of usage of a helicopter, usage monitoring has the potential to provide benefits to helicopter operators in terms of both operating costs and flight safety.

Helicopter usage monitoring (UM) can be considered to be part of a larger field known as Health and Usage Monitoring (HUM) as illustrated below. UM, in the context of structural usage monitoring*, can be further sub-divided into Flight Condition Monitoring (FCM) and Flight Loads Monitoring (FLM) which were defined in Sec. 2.5. HM can also be divided into a range of sub-elements, but such details are not shown in the figure below.



Military helicopter operators in the UK and the USA are actively examining the airworthiness and cost benefits of permanently installed UM systems, both as stand-alone systems and as elements of HUM systems. Barndt [12] indicated that the U.S. Navy intends to fit stand-alone usage monitors in all its helicopters. UM, within the context of HUM systems, is reviewed by the author in a companion document [13]. Because of the large database generated when UM systems are installed fleet-wide, it becomes practical to refine lives in operating hours according to the measured worst-case usage severity, or to replace individual components according to their usage history if *Parts Life Tracking* is implemented.

Conventional FLM normally requires strain gauges (or other sensors) to be attached to some rotating components and their outputs transferred by slip rings or telemetry transmitters to stationary receiving equipment. It is widely accepted that it would be impractical to maintain such measuring systems serviceable over the long periods required for permanently installed systems.

Some advanced R&D, such as that currently being undertaken at Kaman Aerospace by Gunsallus [14,15], on the synthesis of loads experienced on rotating components from loads measured on static components could greatly alleviate the current impracticality of applying

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* Structural components are here defined to comprise rotor system components (including rotor control linkages), main rotor mast and tail rotor output shaft (normally sub-elements of the respective gearboxes), and airframe components (including those relating to the undercarriage).

A broad definition of *usage monitoring*, to include both FCM and FLM is adopted here. It is to be noted that many structural engineers apply the term *usage monitoring* only to FCM.

FLM to permanently installed UM systems. The synthesis technique provides significant scope to place load sensors in benign locations and to minimise the number of sensors required. A stand-alone Helicopter Automatic Load Monitoring and Recording System[16] (HALMARS), commercially available from Kaman Aerospace, performs most of the data processing in flight.

Gunsallus refers to the load synthesis method as "holometrics" (from "holos" meaning *the whole* and "metrics" meaning *measurement*). The heart of the Kaman system is the proprietary software which enables the time histories of loads on rotating components to be synthesised from loads measured on non-rotating components. It is also applicable to synthesising some fixed system loads from other loads measured for the fixed system. Holometrics is a refinement of a linear regression analysis. The system is calibrated from flight data to provide calibration coefficients. The coefficients are derived by statistical methods which employ information conditioning to remove redundant information. Gunsallus formulated the holometrics idea from his earlier work on tuning rotor blades (the tuning typically uses airframe vibration data). Gunsallus originally used a Fast Fourier Transform (FFT) approach but did not like it because it could not provide results in real-time. Now he has dispensed with the FFT method and uses a real-time approach.

Typically, a 100 to 400 Hz sampling rate is required for helicopter structures. If data are reduced to peak and valley information, two readings per cycle would have to be retained. If data are reduced to a life expenditure reading, an update once per cycle would be required. Typically four strain gauges would be used to synthesise the time histories of 20 loads.

Gunsallus has performed a modal analysis justification of his techniques. This provides a derivation of coefficients from first principles.

For calibration purposes a set of flight manoeuvres, which would excite as many modes as possible, would be selected.

MDHC was involved with the U.S. Army in a program to evaluate HALMARS on the Apache helicopter. Toosi[17] indicated that MDHC's first impression was that the Kaman system worked satisfactorily for the Apache. The program was intended to resolve:

- Whether it is feasible to relate main rotor loads to fuselage loads, tail rotor loads to fuselage loads and some fuselage loads to other fuselage loads.
- Whether the system behaves, within useable limits, the same for all aircraft in the program.

Both fuselage and rotating component loads were measured. The relationship between dynamic and static system loads can be expressed simply as:

$$D = CS$$

where
- D is the dynamic system load matrix
- S is the static system load matrix
- C is the transfer matrix

In respect of the dynamic system load matrix to be evaluated, the repeatability of the transfer matrix C is to be assessed.

The longer term aim is to produce a system which can be permanently installed. It will be necessary to establish what extra sensors are required and whether the results are consistently conservative. If an unexpected fatigue failure occurred in a component whose load history

had not been monitored, it may be possible to work out the required transfer function after the failure occurred and then regenerate the load history preceding the failure from the other load history records.

Buckner [18] (U.S. Army ATCOM) indicated that he was very impressed with the results achieved to this stage in the evaluation of the Kaman HALMARS on the Apache helicopter. He passed selected flight data to Kaman and was surprised by the close agreement between the rotating component loads data synthesised by Kaman and actual measured rotating component loads data he had retained. Buckner sees this approach as the way ahead for helicopter life monitoring in the future. He indicated a liking for the mathematical quantifiability of the Kaman approach.

Andrews of MJAD has been undertaking promising research on a transfer function technique which directly relates the fatigue life expenditure of rotating or fixed system components to fixed system loads.

As the application of the Kaman and MJAD techniques is relatively new to the helicopter structural integrity application, there is great interest in further assessing the merits of these methods as they mature.

4. BLACK HAWK AND SEAHAWK COMPONENT INTEGRITY

During the course of the author's discussions with U.S. Army and U.S. Navy representatives, comments were made on structural and mechanical integrity problems that had been experienced with Black Hawk and Seahawk helicopters in the USA. A summary of these comments is provided below.

AATD engineers [20] indicated that the engines and gearboxes for the UH-60 series helicopters have had a good reliability record. However diagnostics for checking the engine electronic control unit while it is installed in the aircraft are inadequate. About half of the engine control unit removals reveal no fault with the unit.

NAWC staff [21] indicated that the following problems had arisen in respect of the Seahawk / Black Hawk transmission system:

- Spalling of tooth in starboard side input pinion in main gearbox.
- High speed shaft failure in input module.
- Tail gearbox output shaft failure*.

* The failure occurred in a Peoples Republic of China S-70C-2 Black Hawk at 350 airframe hours in the 1987/88 time-frame. Recently (June 1993) a second failure of a tail rotor output shaft occurred in a US Army EH-60 Black Hawk (at a component time of 580 hours) as it was coming in to land in New York state. Both the Chinese and the USA failures occurred due to fracture of the Gear Bevel Output Tail Rotor Gearbox Part No. 70358-06620-101. The failure of the Chinese Black Hawk was attributed by Sikorsky to a manufacturing defect. Sikorsky now manufactures an upgraded version of this component (Part No. 70358-06620-102.

- Failure of one or two hanger bearings. (It is likely that the regular water wash which is given to each aircraft has removed grease originally packed into the bearings, there being no facility for in-situ re-greasing.)
- Spline wear in the oil cooler blower shaft. (The problem has been blamed on machining technique. The machining technique has been changed but many original shafts are still in service. Currently the mating spline shafts are marked and separation of the marks on these shafts indicates excessive wear.)
- Corrosion around main gearbox mounting feet.
- Oil line chafing in the tail area.
- Spalling of integral race bearing (about 50 events detected by chip lights).
- Spacer wear in accessory module (not a flight safety issue).

According to Immen[9], the U.S. Army has experienced corrosion problems with the main support bridge. In the past, fatal UH-60A accidents have been attributable to a rotor spindle and a stabilator failure, but any problems which contributed to these accidents have been resolved.

According to Elber[19], a number of structural integrity problems have arisen in respect of the UH-60A helicopter since it came into service:

> ***Main Rotor Spindles:*** The original life of the main rotor spindles (Part No. 70102-08116-047) for the U.S. Army UH-60A Black Hawk was 6700 hours but this was subsequently reduced to 3500 hours. The main problem is to keep the bearing alive, dust ingestion being the major cause. The spindle problem had, in the past, been accentuated by droop stop pounding which had occurred particularly when the helicopter was taxiing in a rearward direction up an incline to fuel dumps. Over 30% of the spindles are rejected at the 500 hour inspection. The spindles cost about USD 10,000 each (USD 40,000 per set). According to Elber, Sikorsky reconditioning costs are virtually the same as that for purchasing new spindles. Elber believes the spindle life may be reduced to 200 hours.
>
> ***Main Rotor Cuff:*** A main rotor cuff failure has occurred; it was a complete surprise.
>
> ***Main Support Bridge:*** Elber commented that it was very important that the main support bridge which is made of aluminium, be correctly installed. The main support bridge carries the main servos which drive the swashplate.
>
> ***Main Beam:*** Premature failures initiated by scratches (such as via a spanner carried by an Army maintenance person) had occurred in the main beam. Elber suggested that a clear plastic coating could be used to damage-proof this component.

According to Barndt[12] the SH-60B airframe has been qualified for 10,000 hours life. To qualify this airframe for operation to the year 2015 will require the airframe to be re-tested by Sikorsky. Barndt indicated that the SH-60 airframe has a high level of redundancy; cracks can be safely monitored by inspection methods.

5. CONCLUSIONS

(a) Military helicopter operators in the USA and UK have adopted policies to substantiate the design lives of components in their major fleets, usually by undertaking in-flight parameter measurement programs.

(b) Life substantiation programs usually involve the fitting of monitoring equipment in a small number of helicopters whose operations are representative of fleet operations. The duration of the data collection would typically be about 200 flying hours per aircraft in the measurement program.

(c) Military operators in the USA and the UK consider in-flight data measurement programs to be superior to pilot questionnaire usage surveys. However the latter are undertaken in some instances because they are less costly. Questionnaire forms are often used to provide supplementary data in support of in-flight measurement programs.

(d) Helicopter life substantiation programs are undertaken to ensure component retirement times are conservative. These programs may result in the shortening of the retirement times for some components if measurements indicate that their loading is more damaging than had been assumed.

(e) Component life extension, based on the results of a substantiation program, is viable only if a reliable and sufficiently large data set is available.

(f) The life substantiation method adopted by military helicopter operators in the USA differs significantly from that employed by operators in the UK. In the USA the most common approach is to measure the flight condition usage spectrum and recalculate lives based on the relationship between flight condition and component life expenditure. That relationship is derived from the manufacturer's loads survey on the prototype helicopter. In the UK the most common approach is to measure the significant flight loads and re-calculate lives directly.

(g) A secondary aim of some helicopter life substantiation programs, undertaken by military operators in the USA, is to check whether there are any significant differences between the maximum loads generated for each flight condition for helicopters flown by military pilots and those generated in the manufacturer's loads survey. A secondary aim of similar programs undertaken in the UK is to identify those manoeuvres responsible for major fatigue damage and, if possible, identify refinements to normal operations to reduce the rate of fatigue damage accumulation.

(h) Research currently being undertaken on the synthesis of loads on rotating components from loads measured in the static system, may overcome some of the major concerns relating to the practicality of measuring important structural loads in the operational environment. The synthesis technique provides significant scope to place load sensors in benign locations and to minimise the number of sensors required. Developments in this area may influence the technologies adopted for structural usage monitoring in the longer term.

(i) In the future, military operators are likely to purchase helicopters with permanently installed Health and Usage Monitoring Systems (HUMS). While the "usage" element of currently available systems is deficient, R&D moves afoot should rectify this situation before the turn of the century. When fleetwide quantitative usage data become available from HUMS, the process of component life substantiation, or component retirement according to actual usage, will be streamlined.

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Military operators normally undertake programs to substantiate the fatigue lives of life-limited components in their major helicopter fleets. During recent visits to military helicopter representatives in the USA and the UK, the author discussed the motivation and the technical approach adopted by these operators for helicopter component life substantiation. Issues and programs of particular relevance to the Australian Defence Force are examined in this document.

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